High-resolution imaging of MRAM device switching using photoemission electron microscopy

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INTRODUCTION

We have used photoemission electron microscopy (PEEM) to image the magnetization reversal process for a wide range of specially prepared, patterned thin-film MRAM devices. Variations in the switching fields have been noted for the members of arrays of each pattern. Because the samples are prepared without the usual protective overlayers and wiring levels, it was possible to obtain accurate SEM images of the island geometry, allowing direct correlation between geometrical properties and magnetic switching characteristics. We discuss the extent to which switching characteristics can be predicted from the observable island shape, and also the direct observation of the effects of shape and size on the spread and quality of the switching event.

MOTIVATION

Recent advances in magnetic tunneling junction materials have led to a surge in development efforts aimed at fabrication of magnetic random access memory devices (MRAM). Although there are many challenges to be overcome before success can be claimed, the principle issue in all of the designs that have been proposed to date is one of uniformity as regards the writing process. Specifically, in order for a specific cell to be written (i.e. force a given magnetic configuration by application of solenoidal fields from an array of thin-film wires) in such a way so as to not disturb the state of neighboring cells, the magnetic switching fields of the devices in the array must be identical to within tight tolerances.

Several approaches have been used in the study of the magnetic control of arrays of magnetic tunnel junction (MTJ) devices. Most straightforward of these is simply to fabricate functioning devices and directly measure the switching fields for each of many MTJs. However, this is time-consuming (requiring many steps in order to construct a working chip) and less direct in that the devices under study are not inspectable since they are buried under various connection and passivation layers. These studies do give estimates of spreads in properties, and in some sense are the most relevant measure of progress in device fabrication. Another method that has been used with great success is direct measurement of the switching properties of large arrays of junctions using magnetometry, such as SQUID, VSM or AGM. Here, one assumes that the observed spread in switching fields (as evidenced by a non-square switching hysteresis loop) is indicative of non-uniformity in the array. Variables such as junction shape, aspect ratio, scale size, material choices, layer thickness and so on can be related quickly and easily to magnetic control. Since this method deals with average properties of the junction array, it cannot answer questions about individual junctions and the effect that specific defects might have on its magnetic properties.

In this experiment we have used PEEM to directly observe the state of magnetization of individual magnetic islands. We are able to correlate shape, size and aspect ratio to the switching

field in magnitude and distribution, and in addition we can also study in detail the imperfections of each island's shape as well.

RESULTS

Figure 1 shows typical images obtained from the PEEM system. The sample was a 5 nm thick Permalloy film with a 1 nm Pt cap. The film was patterned using a liftoff method using e-beam resist for shape definition. The sample contained four basic shapes (rectangle, hexagon, rhombus and ellipse) ranging in width from 0.2 to 2 microns and aspect ratios of 1,2,3 and 5. We found that to a straightforward calculation of demagnetization field correlates to some extent with the observed switching fields. Further, particularly in the larger islands, we observed that the switching proceeded by formation of complex magnetic structures.

In order to understand the dependence of switching on details of shape, we next concentrated on a population of nominally identical devices. Each of 16 islands was measured by top-down SEM, and the resulting image was used to create a mask for micromagnetic modeling. We found that more than half of the variability in switching field could be explained by shape variations, with the remaining portion presumably due to fluctuations in magnetic properties within the island material.
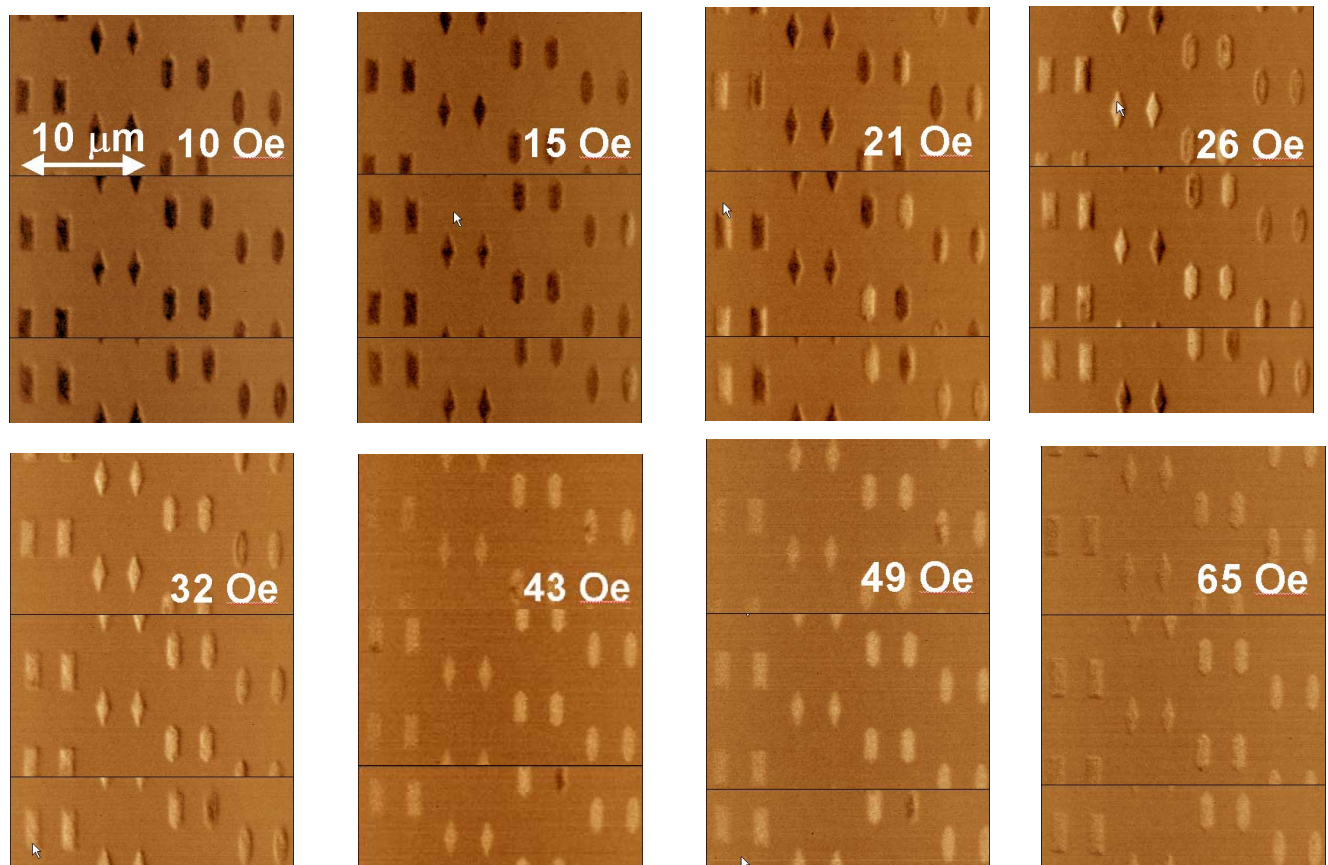

Figure 1. Images of a series of shapes (nominal dimension 1x5 micrometer). Data were taken at remanence after cycling to the field shown in each frame.

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